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(54) **HALL-EFFECT SWITCH CIRCUIT ALLOWING LOW VOLTAGE OPERATION**

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(73) Assignee: **GM Global Technology Operations LLC**

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G01R 33/06 (2006.01)
G01B 7/14 (2006.01)

(52) **U.S. Cl.** **324/251**; 324/207.2

(58) **Field of Classification Search** 324/207.2, 324/251–252

See application file for complete search history.

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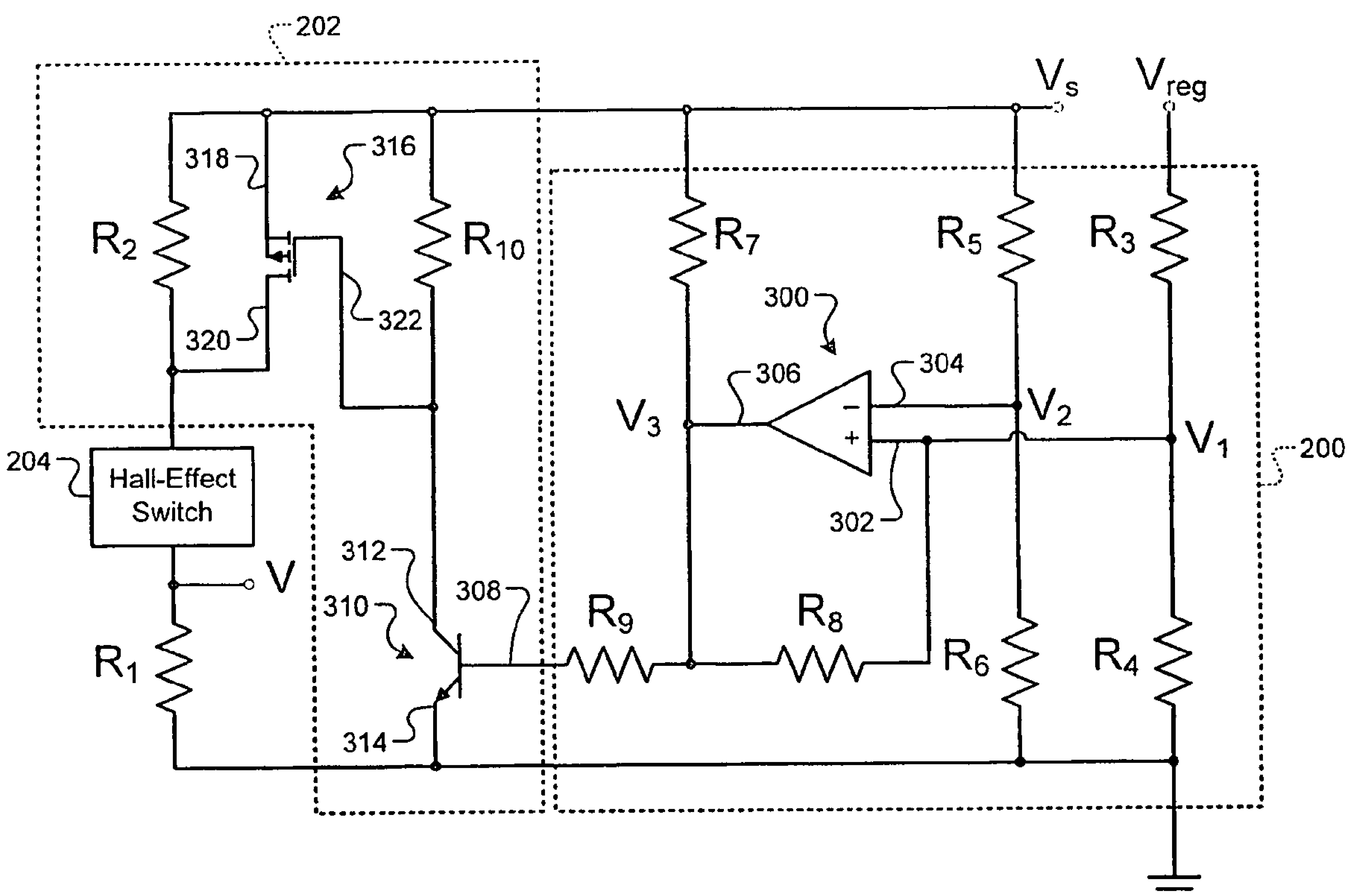
(57) **ABSTRACT**

A hall-effect switching system comprises a hall-effect switch, a voltage comparison module, and a resistance bypass module. The voltage comparison module compares a supply voltage and a reference voltage. The resistance bypass module selectively adjusts a voltage output to the hall-effect switch based on the comparison.

17 Claims, 5 Drawing Sheets



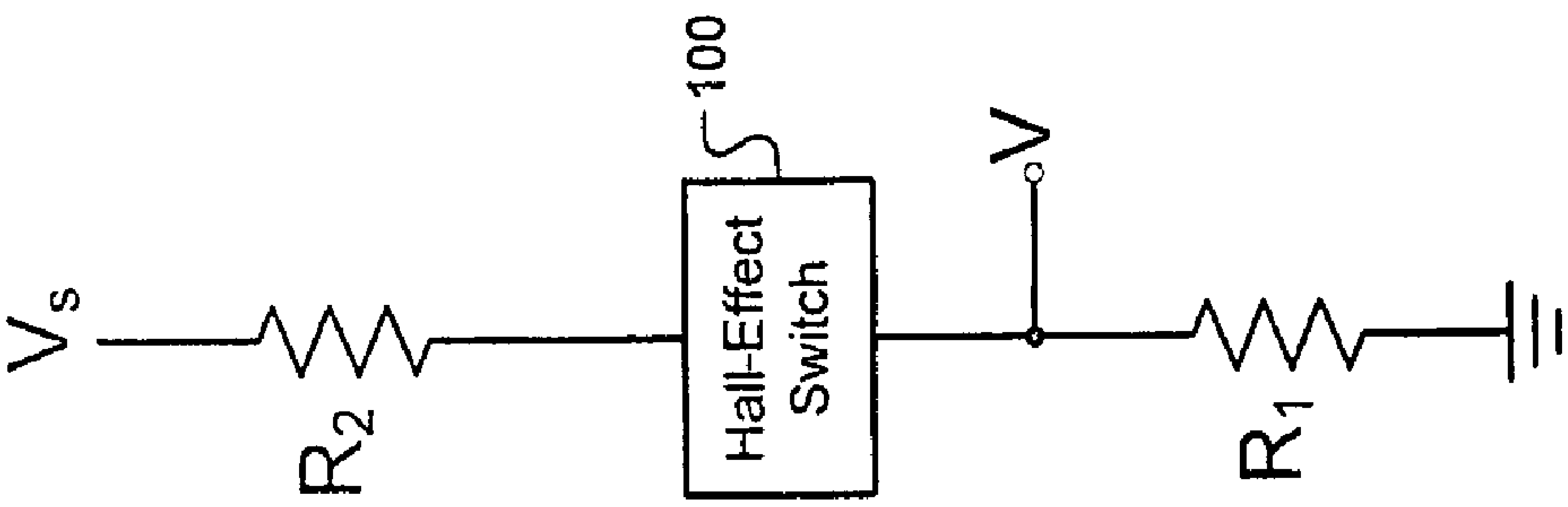


FIG. 1
Prior Art

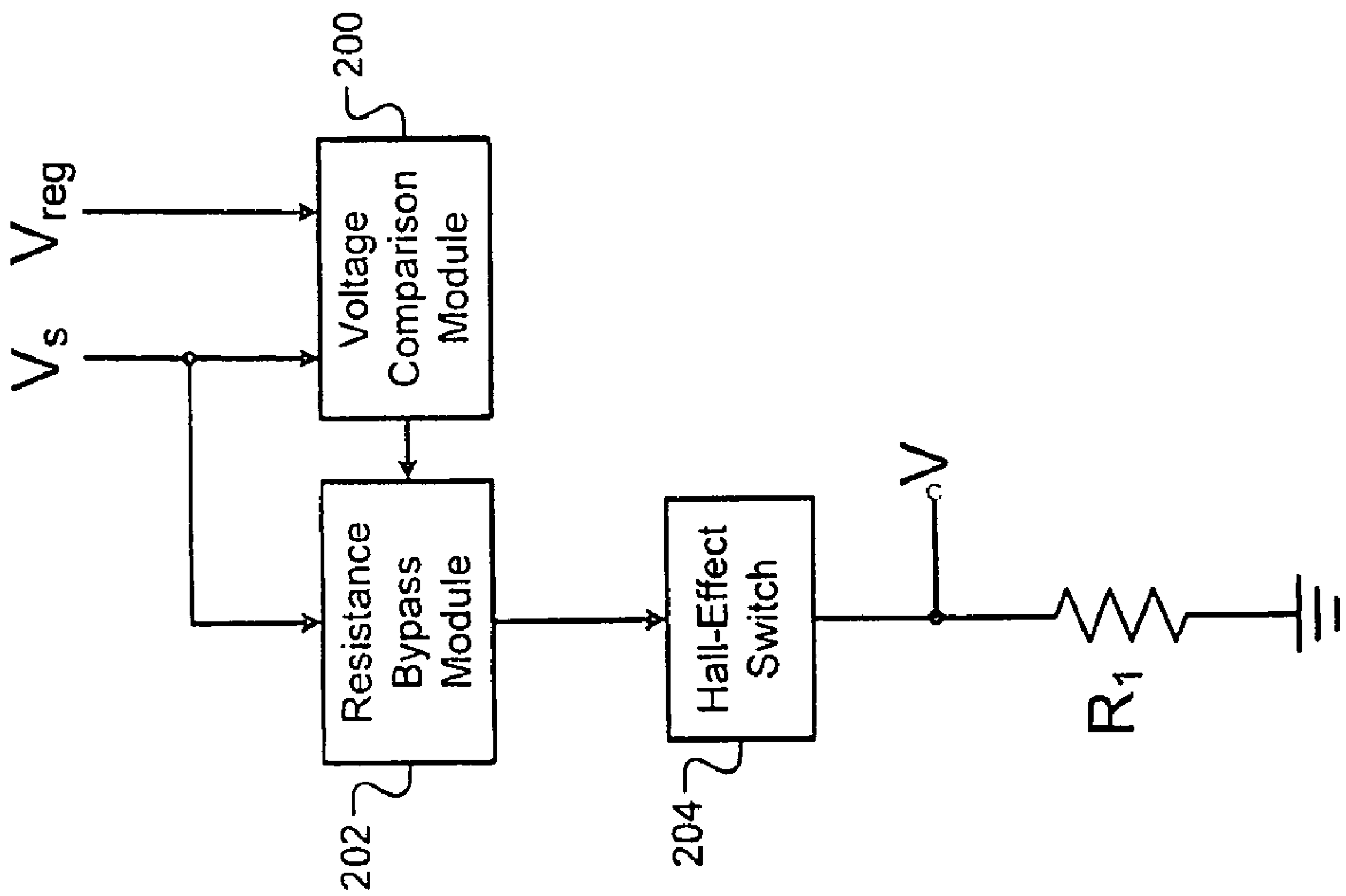
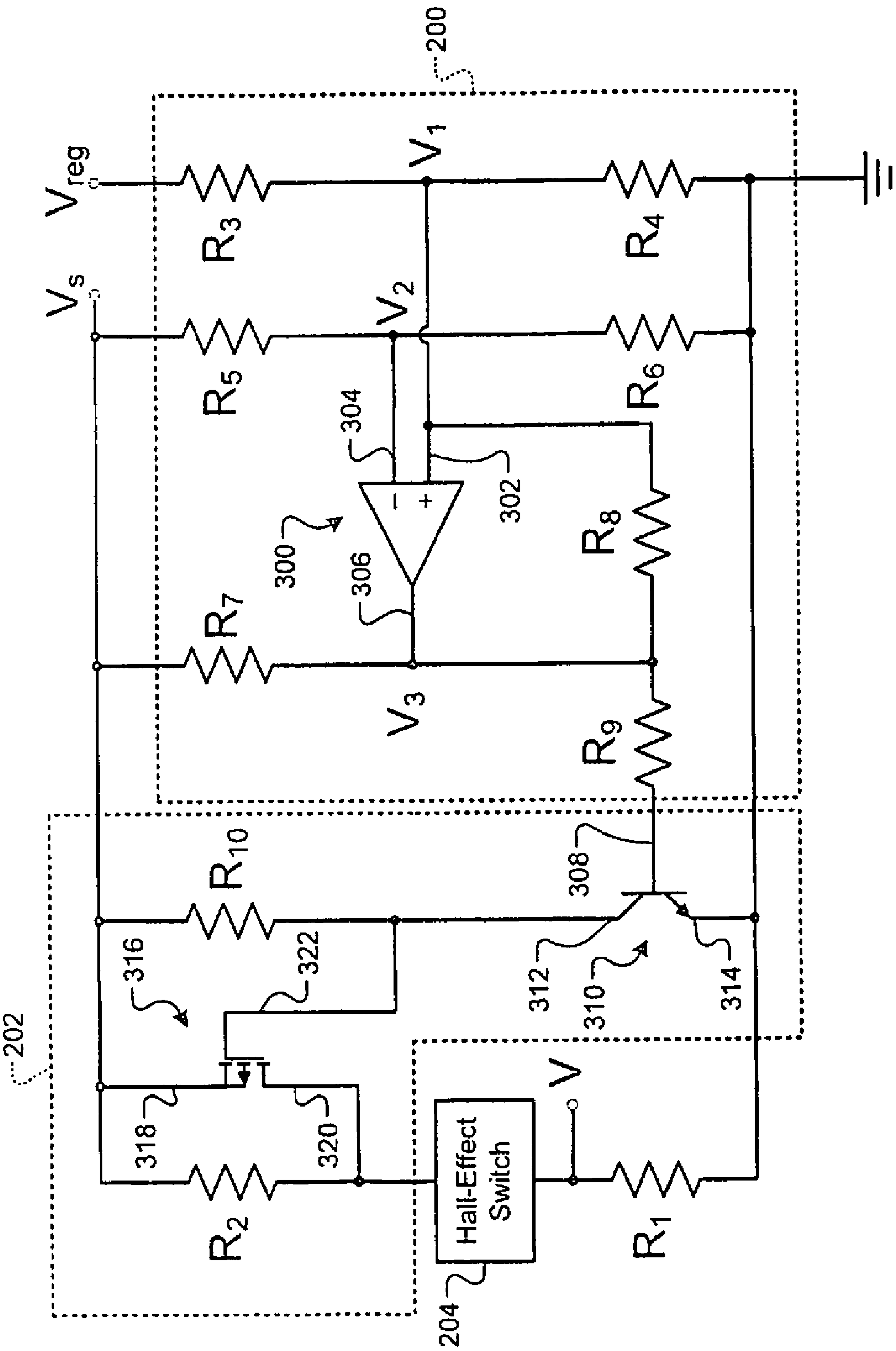

V_{reg}
V_s
200
Voltage Comparison Module
Resistance Bypass Module
202
Hall-Effect Switch
204
V
R_1

FIG. 2



200
202
V_{reg}
V_s
V_1
V_2
V_3
V
R_1
R_2
R_3
R_4
R_5
R_6
R_7
R_8
R_9
R_{10}
300
302
304
306
308
310
312
314
316
318
320
322
204
Hall-Effect Switch

FIG. 3

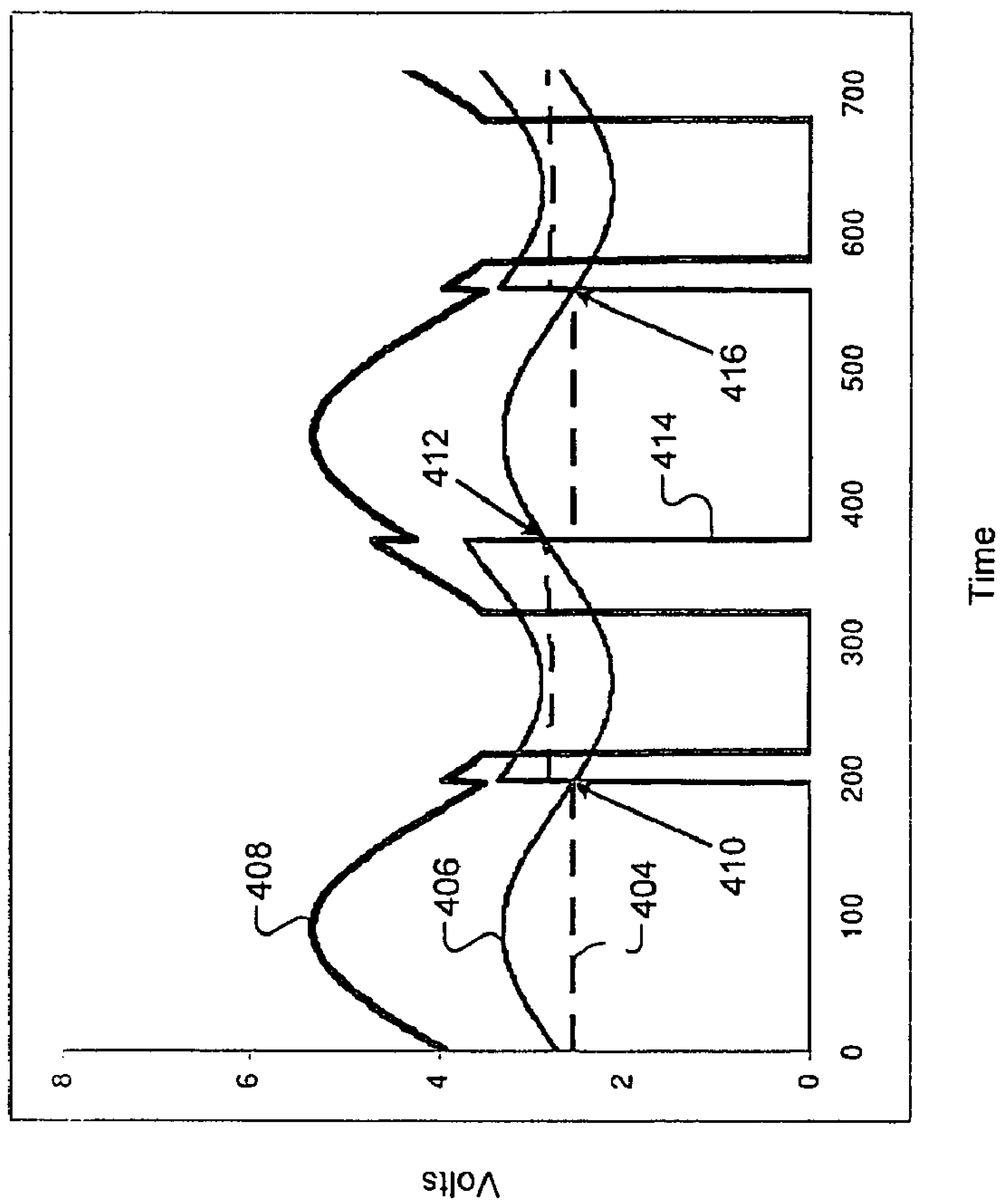


FIG. 4b

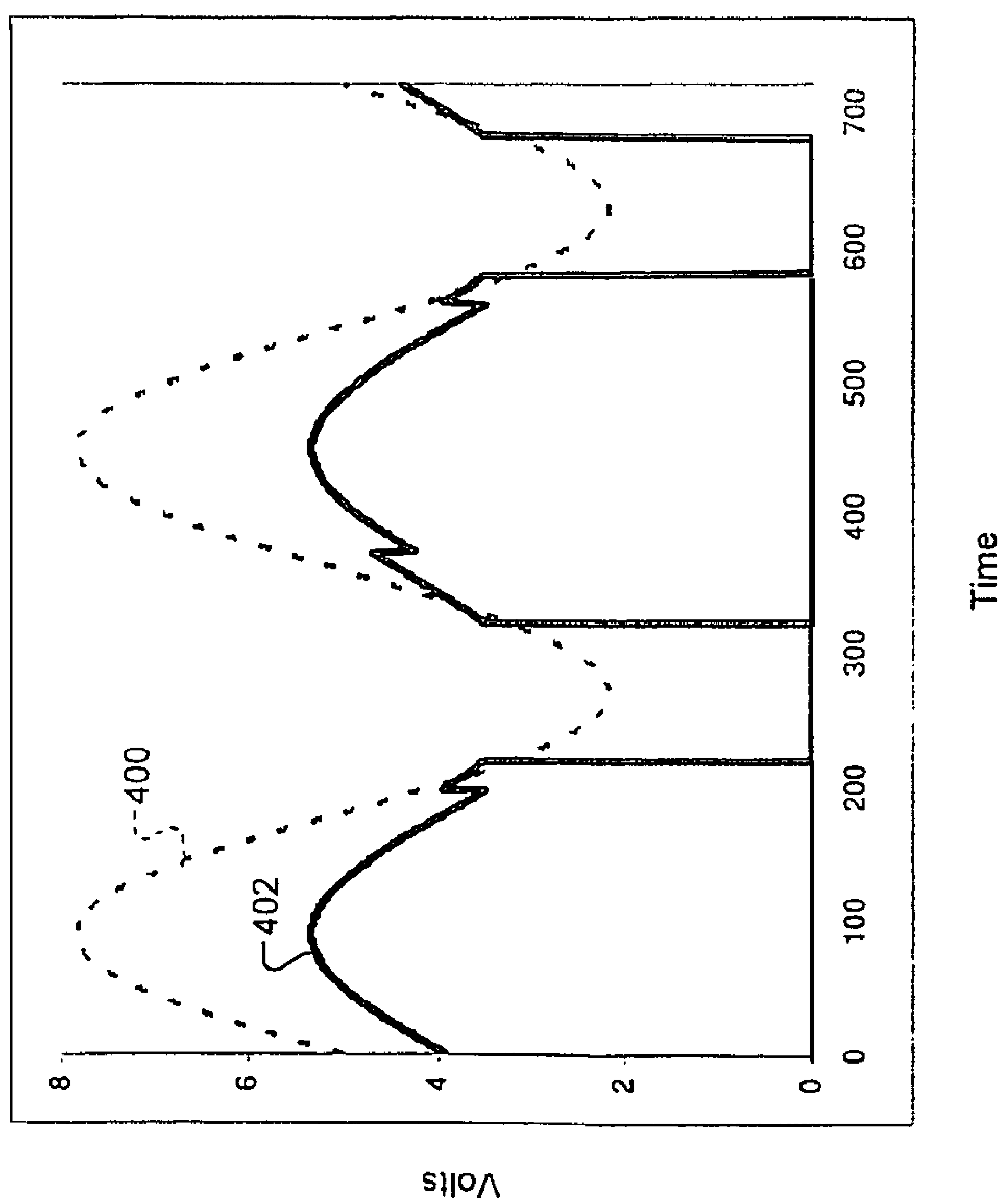


FIG. 4a
Prior Art

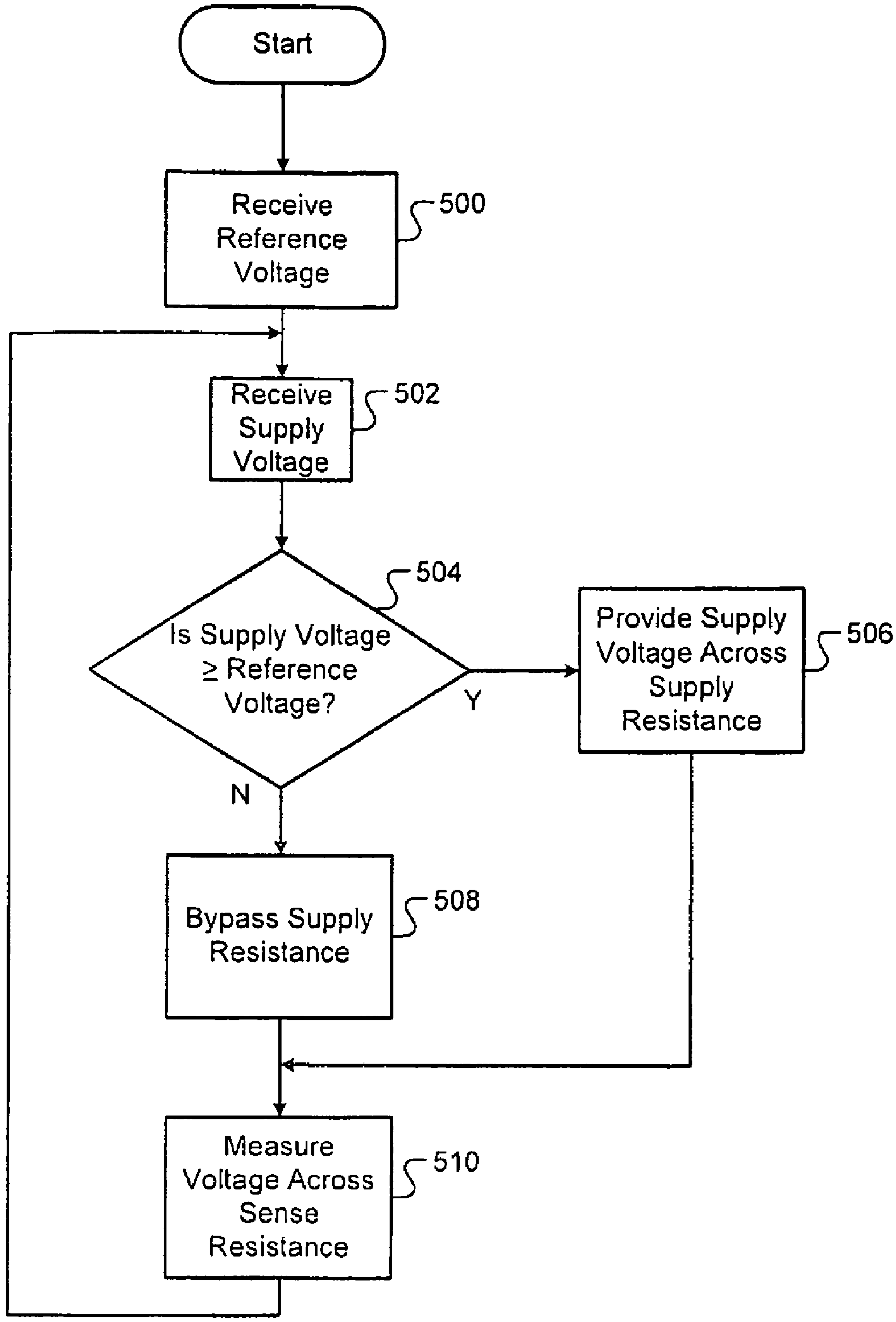

Start
Receive Reference Voltage
500
Receive Supply Voltage
502
Is Supply Voltage ≥ Reference Voltage?
504
Y
N
Provide Supply Voltage Across Supply Resistance
506
Bypass Supply Resistance
508
Measure Voltage Across Sense Resistance
510

FIG. 5

HALL-EFFECT SWITCH CIRCUIT ALLOWING LOW VOLTAGE OPERATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/109,631, filed on Oct. 30, 2008. The disclosure of the above application is incorporated herein by reference.

FIELD

The present disclosure relates to hall-effect switching circuits and low voltage operation.

BACKGROUND

The background description provided herein is for the purpose of generally presenting the context of the disclosure. Work of the presently named inventors, to the extent it is described in this background section, as well as aspects of the description that may not otherwise qualify as prior art at the time of filing, are neither expressly nor impliedly admitted as prior art against the present disclosure.

Referring now to FIG. **1**, a functional block diagram of a hall-effect switching circuit is shown. A hall-effect switch **100** switches between current states. The current states are based on changes of a magnetic field near the hall-effect switch **100**. One end of a sense resistance R_1 is connected to a low side of the hall-effect switch **100**. Another end of the sense resistance R_1 is connected to ground. A voltage V is measured across the sense resistance R_1 to determine the current state provided by the hall-effect switch **100**.

One end of a supply resistance R_2 is connected to a high side of the hall-effect switch **100**. Another end of the supply resistance R_2 is connected to a voltage source, V_s. A supply voltage across the supply resistance R_2 is determined by the voltage V_s.

SUMMARY

A hall-effect switching system comprises a hall-effect switch, a voltage comparison module, and a resistance bypass module. The voltage comparison module compares a supply voltage and a reference voltage. The resistance bypass module selectively adjusts a voltage output to the hall-effect switch based on the comparison. In further features, the voltage comparison module determines when the supply voltage is less than or equal to the reference voltage, and adjusts the voltage output based on the determination. In other features, the reference voltage is adjusted based on the comparison.

In further features, the voltage comparison module determines when the supply voltage is greater than or equal to the adjusted reference voltage, and adjusts the voltage output based on the determination. In other features, the resistance bypass module increases the voltage output based on the comparison. In other features, the resistance bypass module includes a transistor and a resistance in parallel, and the transistor switches states based on the comparison.

In further features, the resistance bypass module includes a second transistor that selectively biases the transistor based on the comparison. In still further features, the voltage comparison module includes an operational amplifier that selectively biases the second transistor based on the comparison.

A hall-effect switching method comprises comparing a supply voltage and a reference voltage, and selectively adjusting a voltage output to a hall-effect switch based on the comparison. In further features, the hall-effect switching method further comprises determining when the supply voltage is less than or equal to the reference voltage, and adjusting the voltage output based on the determination. In other features, the hall-effect switching method further comprises adjusting the reference voltage based on the comparison.

In further features, the hall-effect switching method further comprises determining when the supply voltage is greater than or equal to the adjusted reference voltage, and adjusting the voltage output based on the determination. In other features, the hall-effect switching method further comprises increasing the voltage output based on the comparison. In still other features, the hall-effect switching method further comprises switching states of a transistor that is connected in parallel with a resistance based on the comparison.

In further features, the hall-effect switching method further comprises selectively biasing the transistor by switching states of a second transistor based on the comparison. In still further features, the hall-effect switching method further comprises adjusting an output of an operational amplifier based on the comparison, and selectively biasing the second transistor based on the output.

Further areas of applicability of the present disclosure will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples are intended for purposes of illustration only and are not intended to limit the scope of the disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure will become more fully understood from the detailed description and the accompanying drawings, wherein:

FIG. **1** is a functional block diagram of a hall-effect switching circuit according to the principles of the prior art;

FIG. **2** is a functional block diagram of a hall-effect switching circuit according to the principles of the present disclosure;

FIG. **3** is an exemplary circuit schematic of a hall-effect switching circuit according to the principles of the present disclosure;

FIG. **4***a* is an exemplary graphical depiction of voltage measurements of a hall-effect switching circuit according to the principles of the prior art;

FIG. **4***b* is an exemplary graphical depiction of voltage measurements of a hall-effect switching circuit according to the principles of the present disclosure; and

FIG. **5** is a flowchart depicting exemplary steps performed by a hall-effect switching circuit according to the principles of the present disclosure.

DETAILED DESCRIPTION

The following description is merely exemplary in nature and is in no way intended to limit the disclosure, its application, or uses. For purposes of clarity, the same reference numbers will be used in the drawings to identify similar elements. As used herein, the phrase at least one of A, B, and C should be construed to mean a logical (A or B or C), using a non-exclusive logical or. It should be understood that steps within a method may be executed in different order without altering the principles of the present disclosure.

As used herein, the term module refers to an Application Specific Integrated Circuit (ASIC), an electronic circuit, a processor (shared, dedicated, or group) and memory that execute one or more software or firmware programs, a combinational logic circuit, and/or other suitable components that provide the described functionality.

A hall-effect switching circuit may include a hall-effect switch, a voltage source, and resistances. The hall-effect switch changes current states based on changes of a magnetic field. The hall-effect switch switches between current states when the voltage across the hall-effect switch is greater than a minimum value. The minimum value depends on characteristics of the hall-effect switch. The voltage across the hall-effect switch depends on the values of the voltage source and the resistances connected to the hall-effect switch.

If the voltage across the hall-effect switch is less than the minimum value, then the hall-effect switch will not switch between current states. The voltage provided by the voltage source in the present disclosure is compared to a reference voltage. If the voltage from the voltage source is not greater than the reference voltage, then the voltage across the hall-effect switch may be increased to enable operation of the hall-effect switch.

Referring now to FIG. **2**, a functional block diagram of a hall-effect switching circuit according to the principles of the present disclosure is shown. A voltage comparison module **200** compares a supply voltage V_s to a reference voltage (V_{reg}). When V_s is less than V_{reg}, a resistance bypass module **202** may allow a higher voltage applied to a hall-effect switch **204**. For example only, the voltage comparison module **200** may trigger the resistance bypass module **202** when V_s is less than V_{reg}. The resistance bypass module **202** may lower the resistance between V_s and the hall-effect switch **204**.

The voltage across the hall-effect switch **204** increases based on the lowered resistance. The voltage across the hall-effect switch **204** may be increased so that the hall-effect switch **204** may switch between the current states. A voltage V is measured across a sense resistance R_1 to determine the current state provided by the hall-effect switch **204**.

Referring now to FIG. **3**, an exemplary circuit schematic of a hall-effect switching circuit according to the principles of the present disclosure is shown. The voltage comparison module **200** may include voltage dividers, an operational amplifier **300**, and resistances R_3, R_4, R_5, R_6, R_7, R_8, and R_9 to compare V_s and V_{reg}. For example, V_{reg} may be divided by resistances R_3 and R_4 to generate a voltage V_1. V_s may be divided by resistances R_5 and R_6 to generate a voltage V_2. V_1 and V_2 may be compared by using other methods.

The operational amplifier **300** receives V_1 as an input to a non-inverting terminal **302** and V_2 as an input to an inverting input terminal **304**. The operational amplifier **300** determines whether V_2 is greater than V_1. An output voltage V_3 of the operational amplifier **300** is based on whether voltage V_2 is greater than V_1.

A resistance R_7 is connected between an output terminal **306** of the operational amplifier **300** and V_s. A resistance R_8 is connected between the output terminal **306** and the non-inverting input terminal **302**. A resistance R_9 is connected between the output terminal **306** and a base terminal **308** of a bi-polar junction transistor (BJT) **310**. When the operational amplifier **300** determines that V_2 is less than or equal to V_1, then V_3 is high. If V_2 is greater than V_1, then V_3 is low. When V_3 is high, V_1 increases via feedback voltage across resistance R_8 (i.e. V_1 is adjusted based on V_3). In other implementations, V_1 may not be adjusted by V_3.

A resistance R_{10} is connected between a collector terminal **312** of the BJT **310** and V_s. An emitter terminal **314** of the BJT **310** is connected to ground. When V_3 is generated, the BJT **310** is forward biased and in a saturation mode. The voltage at the collector terminal **312** of the BJT **310** decreases.

A p-channel metal-oxide-semiconductor field-effect transistor (MOSFET) **316** has a source terminal **318**, a drain terminal **320**, and a control terminal **322**. The MOSFET **316** is connected in parallel with R_2. For example, the source terminal **318** is connected to V_s and the drain terminal **320** is connected to a high side of the hall-effect switch **204**. The control terminal **322** is connected to the collector terminal **312** of the BJT **310**. When the collector terminal **312** voltage is lowered, the MOSFET **316** becomes biased to an on state. Accordingly, a resistance between the source terminal **318** and the drain terminal **320** decreases significantly.

When the resistance is lowered, R_2 is by-passed and the voltage supplied to the hall-effect switch **204** increases. In other words, the current will flow through the MOSFET **316** instead of the resistance R_2. R_2 may be by-passed until V_s is greater than V_{reg}, or until V_2 is greater than V_1. The voltage V is measured across R_1 to determine the current state of the hall-effect switch **204**.

Referring now to FIG. **4***a*, an exemplary graphical depiction of voltage measurements of a hall-effect switching circuit according to the principles of the prior art is shown. A voltage supply line **400** depicts exemplary values of V_s. As V_s changes, the voltage across the hall-effect switch **204** changes. A V_H line **402** shows exemplary values of the voltage across the hall-effect switch **204**. A disruption in the V_H line **402** occurs when the voltage across the hall-effect switch **204** drops below a minimum value. For example only, the disruption is shown to occur between roughly 200 ms and 400 ms. During the disruption, the hall-effect switch **204** does not switch between current states.

Referring now to FIG. **4***b*, an exemplary graphical depiction of voltage measurements of a hall-effect switching circuit according to the principles of the present disclosure is shown. A reference voltage line **404** depicts exemplary values of V_1. A voltage supply line **406** represents exemplary possible values of V_2. V_2 and V_1 are compared to determine whether voltage compensation is needed.

When the voltage V_2 line **406** decreases below the reference voltage line **404**, a disruption occurs in a V_H line **408**. For example only, a starting point **410** shows that the voltage V_2 line **406** crosses the reference voltage line **404** at roughly 200 ms. The disruption is compensated for by V_3 going high during the period between the starting point **410** and an ending point **412**.

At the starting point **410**, V_3 goes high because the voltage V_2 line **406** has dropped below the reference voltage line **404**. A voltage compensation line **414** represents exemplary values of V_3. When V_3 is high, the V_H line **408** appears to not have a disruption because the voltage compensation line **414** fills in the missing portion of the V_H line **408**. V_3 continues to be high until the voltage V_2 line **406** is greater than the reference voltage line **404**. For example only, the voltage V_2 line **406** is greater than the reference voltage line **404** between the ending point **412** and a second starting point **416**.

In FIG. **4***b*, the reference voltage line **404** rises to a higher voltage when V_3 is high. Because the reference voltage line **404** rises to a higher voltage level when V_3 is high, the starting point **410** and the ending point **412** are at different voltage levels. In various implementations, the starting point **410** and the ending point **412** may be at the same voltage level.

Referring now to FIG. **5**, a flowchart depicting exemplary steps performed by a hall-effect switching circuit according to the principles of the present disclosure is shown. Control begins in step **500**. In step **500**, control receives the reference voltage. In step **502**, control receives the supply voltage. In step **504**, control determines whether the supply voltage is greater than the reference voltage. If the supply voltage is greater than the reference voltage, then control transfers to step **506**; otherwise, control transfers to step **508**.

In step **506**, control provides the supply voltage across the supply resistance. In step **508**, control bypasses the supply resistance. In step **510**, control measures the voltage across the sense resistance.

Those skilled in the art can now appreciate from the foregoing description that the broad teachings of the disclosure can be implemented in a variety of forms. Therefore, while this disclosure includes particular examples, the true scope of the disclosure should not be so limited since other modifications will become apparent to the skilled practitioner upon a study of the drawings, the specification, and the following claims.

What is claimed is:

1. A hall-effect switching system comprising:

a hall-effect switch that enables and disables current flow between an input of said hall-effect switch and an output of said hall-effect switch;

a voltage comparison module that compares a supply voltage and a reference voltage; and

a resistance bypass module that selectively adjusts a voltage at said input of said hall-effect switch based on said comparison,

wherein said resistance bypass module includes a transistor and a resistance in parallel, wherein said transistor switches states based on said comparison.

2. The hall-effect switching system of claim **1** wherein said voltage comparison module determines when said supply voltage is less than or equal to said reference voltage, and adjusts said voltage at said input based on said determination.

3. The hall-effect switching system of claim **1** wherein said reference voltage is adjusted based on said comparison.

4. The hall-effect switching system of claim **3** wherein said voltage comparison module determines when said supply voltage is greater than or equal to said adjusted reference voltage, and adjusts said voltage at said input based on said determination.

5. The hall-effect switching system of claim **1** wherein said resistance bypass module increases said voltage at said input based on said comparison.

6. The hall-effect switching system of claim **1** wherein said resistance bypass module includes a second transistor, wherein said second transistor selectively biases said transistor based on said comparison.

7. The hall-effect switching system of claim **6** wherein said voltage comparison module includes an operational amplifier that selectively biases said second transistor based on said comparison.

8. A hall-effect switching method comprising:

comparing a supply voltage and a reference voltage; and

selectively adjusting a voltage at an input of a hall-effect switch based on said comparison,

wherein said hall-effect switch enables and disables current flow between said input of said hall-effect switch and an output of said hall-effect switch, and

wherein said adjusting said voltage at said input comprises switching states of a transistor that is connected in parallel with a resistance based on said comparison.

9. The hall-effect switching method of claim **8** further comprising:

determining when said supply voltage is less than or equal to said reference voltage; and

adjusting said voltage at said input based on said determination.

10. The hall-effect switching method of claim **8** further comprising:

adjusting said reference voltage based on said comparison.

11. The hall-effect switching method of claim **10** further comprising:

determining when said supply voltage is greater than or equal to said adjusted reference voltage; and

adjusting said voltage at said input based on said determination.

12. The hall-effect switching method of claim **8** further comprising:

increasing said voltage at said input based on said comparison.

13. The hall-effect switching method of claim **8** further comprising:

selectively biasing said transistor by switching states of a second transistor based on said comparison.

14. The hall-effect switching method of claim **13** further comprising:

adjusting an output of an operational amplifier based on said comparison; and

selectively biasing said second transistor based on said output of said operational amplifier.

15. A hall-effect switching system comprising:

a hall-effect switch;

a voltage comparison module that compares a supply voltage and a reference voltage; and

a resistance bypass module that selectively adjusts a voltage output to said hall-effect switch based on said comparison,

wherein said resistance bypass module includes a transistor and a resistance in parallel, and

wherein said transistor switches states based on said comparison.

16. The hall-effect switching system of claim **15** wherein said resistance bypass module includes a second transistor, wherein said second transistor selectively biases said transistor based on said comparison.

17. The hall-effect switching system of claim **16** wherein said voltage comparison module includes an operational amplifier that selectively biases said second transistor based on said comparison.

* * * * *